1 lydrogen Effects on GaAs Device Reliability

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Abstract

It has been observed that GaAs devices mounted in hermetically sealed packages, and exposed to burn-in and lifetest temperatures as low as 125°C, exhibit performance degradation in both RF and DC characteristics after relatively short periods of test lime (500 hours)[1,2]. Further investigations have led to the determination that hydrogen gas was the cause of the observed degradation. This degradation was later observed to be common to most GaAs devices utilizing the industry standard gate metallization structures of Ti/Pt/Au or Ti/Pd/Au [1-18].

This paper will provide a discussion and summary of the general understanding of the failure mechanisms associated with this phenomenon and the current efforts in the industry to find a solution.

Introduction

GaAs devices subjected to reliability lifetests under Nitrogen gas flow have shown excellent reliability. }Im'ever, r'weal tests of GaAs devices in scaled hermetic packages or in the presence of hydrogen gas have shown degradation in both RF and DC device characteristics. The effects of hydrogen on the performance and reliability of semiconductor devices have been reported over the last few years[3,4], but it was only recently that the detrimental effects of hydrogen on GaAs reliability have come to light, The source of the problem was determined to bc hydrogen gas that had been absorbed in the package metals (Kovar, plating, etc.). Studies of hydrogen outgassing performed on hermetic A40 (Al/Si) and Kovar packages, showed Ni/Au plated Kovar packages to bc, by far, the greatest source of hydrogen[3,4]. Other studies have shown other materials used in RF modules 10 bc substantial contributors to the hydrogen concentration and gain of the device. Hydrogen effects in FETs with either Pt or Pd gate metals have been observed; however the effect does seem to be universal to all devices under test[16]. Recent research has concluded that the diffusion of hydrogen may occur at the Pt sidewalls and not at the Au surface of the Au/Pt/Ti gate metal[17].

Other research on GaAs PHEMT and InP HEMT in a hydrogen atmosphere has shown that the drain current may increase in some cases. This observation has led to the conclusion that the hydrogen diffuses into the semiconductor surface where it is thought to change the metal-semiconductor built-in potential[15]. The effects of hydrogenation on n-GaAs platinum-group-metal Schottky barriers have been studied extensively. The I-V characteristics for Ru and Ir contacts were observed to change drastically after exposure to atmospheric pressure hydrogen; the observed changes were thought to be indicative of barrier height and leakage current reductions[9].

Observed Effects on Device Parameters

Lifetests, performed on GaAs MESFETs in 1% H_2 at 200° C for 140 hours, showed an increase in MESFET I_{DSS} and V_{PO} and a decrease in g_m and RF gain[14]. This observation may be explained by hydrogen neutralization of acceptors such as a silicon atom substituting for an arsenic atom, i.e., Si_{As}. This in turn would cause an increase in the net donor concentration, $|N_D-N_A|$ and corresponding increases in I_{DSS} and $|V_{PO}|$.

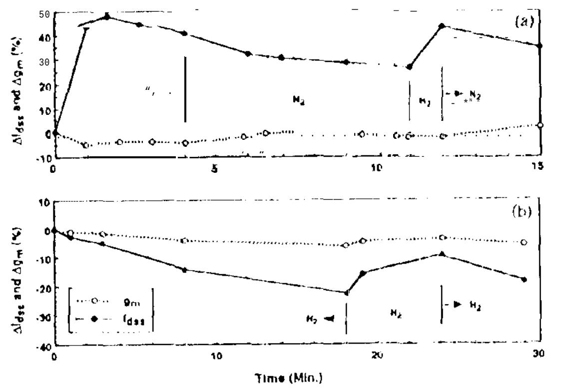

Figure 1. Changes in peak transconductance, gm, and drain current at zero gate bias, Idss, of both (a) InP HEMT and (b) GaAs PHEMT under nitrogen and 4% hydrogen treatments at 270°C. The devices were unbiased during the treatments. The measurements were performed at room temperature [15].

Tests performed in 0.1 % H_2 at 160°C for up to 1,300 hours caused PHEMT I_{DSS} to decrease [8]. Other investigations have shown MESFETs annealed in 10% H_2 at 140°C and 180°C to have abrupt increases in V_{BGD} and V_{BGS} with simultaneous decreases in g_m, $|V_{PO}|$, and I_{DSS} [2]. This data may be explained by hydrogen neutralization of Si donors and the formation of Si-H complexes[4].

Studies of GaAs PHEMTs annealed in 3% H_2 at 200°C showed a degradation in I_{DSS} by as much as 30%, then a recovery by as much as 90% under a nitrogen purge at 200 °C[6]. Figure 1 shows that plastic (polycyanurate) or that the silver oxides (silver composes about 80% of weight of resin) were bonding 10 the hydrogen during the cure cycle. Further studies are needed 10 determine the usefulness and stability of this material for this application.

Other materials specifically formulated for this application have been developed by some device manufacturers and users, but unfortunately information on these materials is still considered proprietary and not available for release.

Barrier Materials

The presence of the Ti/Pt or Ti/Pd barrier layers in the gate structures has been determined to be an integral part of the observed degradation process[1]; Therefore, the replacement of these materials by an equally stable barrier structure which dots not show the observed effects is highly desirable. Ternary amorphous thin film refractory compounds of

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